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Dynamics and Electro-Mechanical Effects of Liquid Crystal Elastomers Films in Nematic Liquid Crystal

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We experimentally investigated the swelling dynamics of films of liquid crystalline elastomers (LCEs) of a thickness of ~150μm by nematic low molecular weight liquid crystals (LMWLC), 5CB. In monodomain, or single liquid crystal elastomers (SLCE), the director, **n**, was uniformly oriented throughout the film while there was no correlation between the **n**'s in the different domains of a polydomain LCE.

The shape changes during the swelling of monodomain and polydomain are shown in Fig. 1. Here, MONO1 and MONO2 are obtained by slicing parallel and perpendicular to **n** respectively. In the MONO1 samples, a rectangular shape is seen propagating in from the edges of sample. We interpret this to be front propagation of LMWLC into SLCE. The LMWLC fronts propagates into SLCE with the velocities $\dot{V}_x \sim 1\mu m/min$ and $\dot{V}_y \sim 0.33\mu m/min$, that is, transport speed for $\perp$ **n** is about 3-times faster than $\|$ **n**.

The front propagation can be clearly seen in the MONO1 because the orientation of LMWLC propagating into the sample is perpendicular to the SLCE director orientation, i.e., large difference in refractive indices. The similar propagation is observed in first 20 minutes of swelling process in MONO2. But there is big difference of dynamics. In MONO2 buckling instability takes place during the propagation. This is due to the speed differences between the invasion of LMWLC in SLCE and the stretch out of swollen SLCE (with constant thickness). At the steady state, e. g. after 10 minutes, the film becomes flat and buckling stripe disappears.

In swelling of POLY, its shape isotropically expands on average. No front propagation can be observed in sample during swelling process.

We define the length expansion parameter α_i as the ration of the swollen length $l_i(t)$ to the initial length l_i^0. Depending on the slicing direction, i may be x, y or z. The experimental fact shows that the

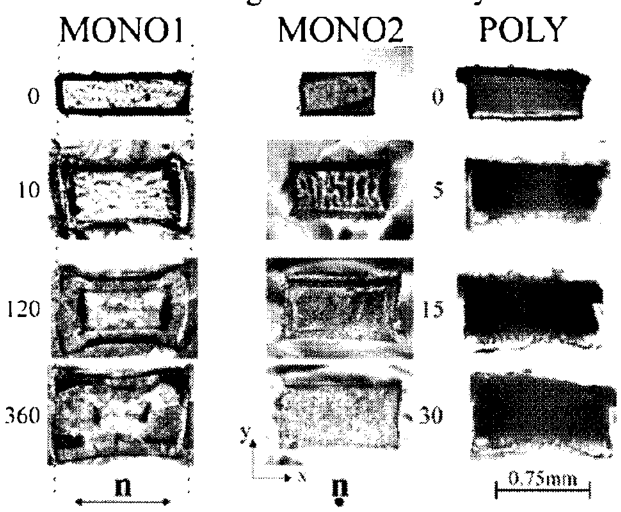

Figure 1. The numbers refer to minutes after the dry LCEs were embedded in 5CB. MONO1, MONO2 and POLY are a planar aligned, homeotropically aligned and polydomain films of a thickness of ~ 150μm.

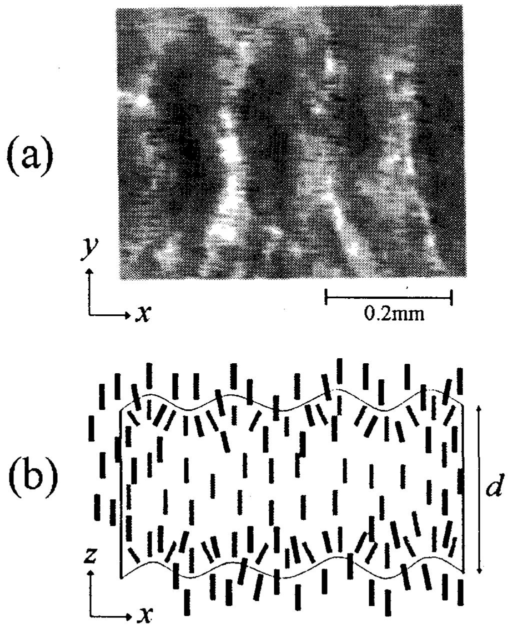

Figure 2. Stripe pattern due to buckling instability observed during swelling process of MONO2 (a). (b) shows a schematic of the top and bottom surfaces buckle in initial stage of swollen MONO2. The dark bar in (b) represents LMWLC molecules.

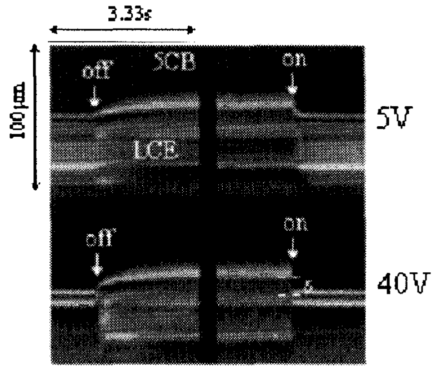

Figure 3. Space-time plot of swollen LCE under an electric field. δ is defined as the variation of shape changes (displacement).

SLCE always expands in direction perpendicular to **n** such that $l_{\perp\mathbf{n}}$ $(t \to \infty) \sim 1.8l^0$ while $l_{\|\mathbf{n}}$ does not change in monodomain samples. The POLY length expands up to $l_{POLY} \sim 1.8l^0$ independent of the directions. The characteristic time for swelling process of MONO2 is $\tau_{M2} = 7.22min$. Due to the reorientation of LMWLC molecules during swelling in MONO1, the swelling time becomes longer: $\tau_{M1} \sim 15.9min$. In POLY sample, since the front propagation is interrupted by domain walls and disclinations, the time for swelling $\tau_P \sim 20.7min$ is longer than MONO1.

We also investigated the electro-mechanical response of swollen LCEs. The experimental fact shows that the threshold field of electro-mechanical effect is about 1.0 *V*, more than 4000 times smaller than that of dry LCEs. Space-time plot of swollen LCE under the electric field is shown in Fig.3. The variation of shape changes δ (displacement) of LCE-5CB boundary is about 13μm (40V). The response time (when the field is turned *on*) of these shape changes is a few milliseconds. On basis of these results, we conclude that swollen LCEs have outstanding potential to make a wide application of low voltage driven artificial muscles.

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